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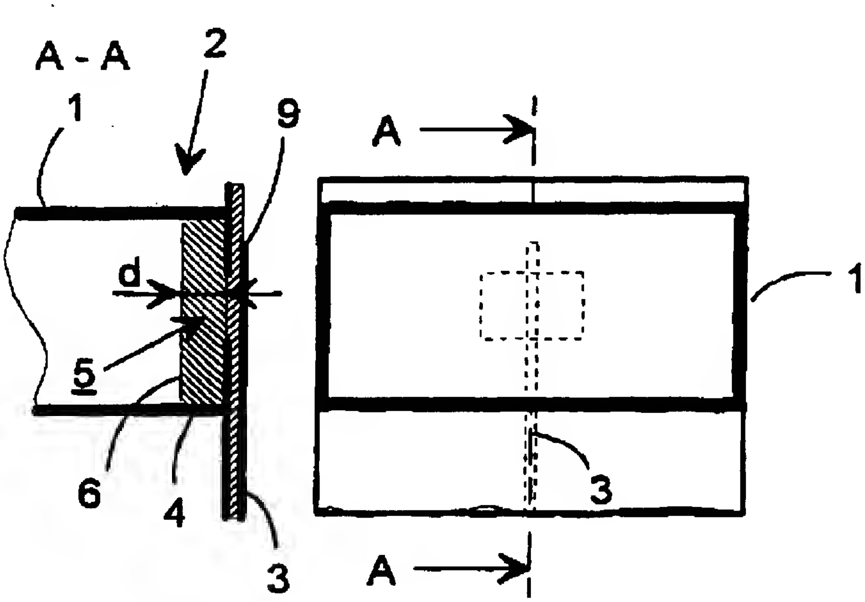

(57) Abstract

The present invention relates to a microstrip-to-waveguide transition in the micro and/or millimetre wavelength range, said transition comprising a waveguide (1), a microstrip (3) placed at one end of the waveguide, and a ground plane (4) with a coupling iris (5) between the microstrip and the waveguide. According to the invention, the transition is provided with a resonator (6) consisting of dielectric material and placed below the coupling iris (5) in the waveguide (1) for the coupling of power via the coupling iris to the resonator and further to the waveguide.

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MICROSTRIP-TO-WAVEGUIDE TRANSITION

The present invention relates to a microstrip-to-waveguide transition as defined in the preamble of claim 1.

Previously known are a few microstrip-to-waveguide transitions used to transfer energy from a microstrip to a waveguide in the micro and millimetre wavelength range. Such known transitions include at least three types: ridge waveguide type transition, fin wire type transition and probe type transition. A feature common to all of these transitions is that they are difficult to manufacture and are not hermetic.

Previously known is also a microstrip-to-waveguide transition in which the transition has been developed from a patch aerial and which comprises a microstrip on a planar substrate above a coupling iris in a ground plane. Moreover, the transition comprises a dipole element (patch aerial) placed below the coupling iris and supported by another planar substrate. A rectangular strip plate (dipole element) on the substrate constitutes a radiating resonator. Such a transition is described in the German patent specification DE 4208 458.

In the transition presented in said specification, power is coupled from the microstrip to the waveguide via a dipole element. Furthermore, according to the specification, the coupling iris must be so dimensioned that the resonant frequency of the iris lies clearly above the operating frequency of the transition. In relevant literature, such a design is regarded as being typical of the iris of patch aerials. Therefore, the physical size of the iris will be relatively small. In addition, in the transition presented in the above-mentioned specification, it is essential that the dielectric constant of the material

between the coupling iris and the dipole element is as low as possible, preferably the material between the coupling iris and the dipole element is air, which has a dielectric constant of 1.

Such a microstrip aerial typically has a very narrow bandwidth, especially when the substrate consists of a material with a high dielectric constant.

Thus, a problem with a transition using a patch aerial is a small bandwidth, in other words, power transfer must be confined to a narrow frequency band. However, in many applications, wide-band operation is needed, so a narrow-band transition cannot be used. On the other hand, the transition needs to be made to precise dimensions to be matched, so an accurate manufacturing process is required.

The object of the present invention is to eliminate the problems referred to above or at least to alleviate them significantly. A specific object of the present invention is to produce a new type of microstrip-to-waveguide transition which can easily be manufactured as a hermetic design and which has a large bandwidth.

A further object of the present invention is to produce a microstrip-to-waveguide transition which is simple and cheap to implement.

As for the features characteristic of the invention, reference is made to the claims.

The above invention relates to a microstrip-to-waveguide transition in the micro and/or millimetre range. The transition comprises a waveguide, a microstrip placed at one end of the waveguide, and a ground plane with a coupling iris between the microstrip and the waveguide. According to the invention, placed below the coupling iris in the waveguide is a resonator made of a dielectric material for the coupling of power via the coupling iris to the resonator and further to the waveguide. Preferably the resonator extends to

the ground plane, leaving between the resonator and ground plane no air gap, which has to be considered in determining the dimensions of the resonator. However, it should be noted that it may be preferable in some solutions to provide an air gap between the resonator and the ground plane.

The bandwidth can be further improved by increasing the thickness of the dielectric plate. When the thickness is increased, the transition requires a larger coupling iris to be matched. Therefore, the resonant frequency of the coupling iris will be close to the operating frequency of the transition. When the dielectric piece has a thickness of $\lambda/4$ - in this application, λ corresponds to the wavelength at the operating frequency of the transition - it has been established that the transition will match best when the resonance of the iris lies below the operating frequency of the transition. In the case of known patch aerials fed via an iris, the iris resonance is generally at a frequency considerably higher than the operating frequency of the transition.

The present invention has the advantage that the bandwidth at the operating frequency is significantly larger than in the case of corresponding hermetic and productive structures. Furthermore, the transition of the present invention is not so sensitive to changes in the production process as previously known microstrip-to-waveguide transitions. Therefore, the present invention makes the manufacture of the microstrip-to-waveguide transition economically more reasonable than before.

In an embodiment of the invention, the dielectric constant of the resonator, ε_r, is about 5 - 15, advantageously about 6 - 10 and preferably about 7.5. The value of the dielectric constant can be selected within the limits permitted by the materials available according to the properties desired in each case, de-

pending on the other aspects of the transition design.

In an embodiment of the invention, the resonator comprises a metal strip placed on the opposite side of the resonator relative to the coupling iris. Typically, the metal strip is very thin and it can be produced by making a desired metal pattern on the surface of the resonator. Further, the ground plane with the coupling iris can be prepared on the opposite surface of the microstrip substrate relative to the microstrip. This makes it possible to avoid adding a separate component, the ground plane, to the transition structure.

In an embodiment of the invention, the width of the metal strip is so chosen that it is smaller than the width of the coupling iris. Thus, the transition has a compact structure and wide bandwidth. Both edges of the passband are steep, and the passband has at least two resonances - one resonance will not provide a similar passband steepness.

In another embodiment, the resonator may comprise a metal strip having a very large width in relation to the coupling iris. In this case the transition has a very wide passband, considering the small size of the structure. Fig . 5 presents a measurement result for a structure with a wide metal strip. Within an electrically short distance, many phenomena occur which together render the transition a wide-band one. A wide metal strip has a larger resonance bandwidth than a narrow one. In the case of a small metal strip, the current distribution is concentrated on both edges as in the case of a microstrip. In a wide metal strip, the current distribution is spread over a larger area, which fits well into the field pattern of the basic waveguide waveform. A wide metal strip is also better at evoking resonant waveforms in the dielectric resonator, broadening the bandwidth of the transition.

It is also possible to increase the bandwidth

by adding parasitic elements beside the metal strip. By means of such elements, when the resonant frequencies of the added parallel elements are adjusted to slightly different values, the bandwidth can be increased to a width as large as three or four times the bandwidth obtained by means of a small metal strip.

A preferred waveguide may be of a rectangular, round, polygonal or elliptic shape in cross-section.

In the following, the invention is described in detail by the aid of examples of its embodiments by referring to the attached drawing, in which:

Fig. 1 presents a transition as provided by the invention,

Fig. 2a and 2b illustrate the quarter-wave transformer effect of a dielectric piece both in void and in a waveguide;

Fig. 3 presents a transition as provided by invention;

Fig. 4 presents a mirror image of the resonator in a transition as provided by invention; and

Fig. 5 presents a measured frequency response characteristic of a transition as provided by invention.

The microstrip-to-waveguide transition presented in Fig. 1 comprises a waveguide 1, a microstrip 3 placed at one end 2 of the waveguide and a ground plane 4 with a coupling iris 5, fitted between the microstrip and the waveguide. Moreover, the microstrip-to-waveguide transition comprises a resonator 6 fitted below the coupling iris 5 and made of a dielectric material, so that power is coupled via the coupling iris to the resonator and further to the waveguide. The distance of the free end 9 of the microstrip, the length of the so-called open stub as measured from the centre of the coupling iris 5 is about $\lambda/4$, bringing the maximum of the magnetic field to the centre

of the coupling iris 5 while the maximum of the electric field occurs at the end of the open stub 9.

Referring to Fig. 2a and Fig. 2b, a dielectric piece having a quarter-wave thickness functions in the transition as a quarter-wave transformer. The situation can be illustrated with a free-space example. The impedance η_0 of free space is 377 Ω, the impedance of the dielectric piece is $\eta_0 / \sqrt{\varepsilon}$, and the impedance seen by the iris is to be 50 Ω. Therefore, the dielectric resonator or quarter-wave transformer, Fig. 2a, should now have an impedance of

$$\frac{\eta_0}{\sqrt{\varepsilon_r}} = \sqrt{\eta_0 \times Z_2}\ ; \text{ where} \qquad (1)$$

ε_r = dielectric constant of the resonator

Z_2 = assumed impedance of the coupling iris; and

η_0 = impedance of free space;

which yields as a suitable dielectric constant value:

$$\varepsilon_r = \frac{\eta_0}{Z_2} = 7{,}5 \qquad (2)$$

Correspondingly, in the situation presented in Fig. 2b, the following equation is obtained for the waveguide:

$$Z_x \times \frac{\eta_0 / \sqrt{\varepsilon_r}}{\sqrt{1 - \left(\frac{f_c}{f \times \sqrt{\varepsilon_r}}\right)^2}} = \sqrt{Z_x \times \frac{\eta_0}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}} \times Z_2}\ ; \qquad (3)$$

where

ε_r = dielectric constant of resonator

Z_x = coefficient by which waveguide's wave impedance is multiplied to obtain characteristic impedance of waveguide;

Z_2 = assumed impedance of coupling iris;

η_0 = impedance of free space;
f = operating frequency; and
f_c = critical frequency

The expression on the left side of the equation is the impedance of a waveguide filled with dielectric material, and the expression on the right side is the square root of the impedance of an air-filled waveguide multiplied by the assumed iris impedance Z_2. Z_x is a coefficient by which the wave impedance of the waveguide is multiplied to obtain its characteristic impedance. Z_x is dependent on the definition of impedance. The iris impedance should be determined using the same impedance definition. Thus, a suitable dielectric constant will be as follows:

$$\varepsilon_r = \frac{Z_X \cdot \eta_0 \cdot \sqrt{1-(\frac{f_c}{f})^2}}{Z_2} + \left(\frac{f_c}{f}\right)^2 \qquad (4)$$

For example, with the power - voltage - impedance definition for a standard waveguide rectangular in cross-section in which the sides of the cross-section measure in the relation a = 2b, Z_x equals 1. In a transition according to the invention, you have a frequency about 1.8 times higher than the critical frequency. In that case, the square root expression yields 0.8. If the impedance visible to the waveguide from the iris is to be 50 Ω, a suitable dielectric constant will be 6. For instance, the dielectric constant of alumina is 9.8, so a quarter-wave transformer made of this material will reduce the waveguide's impedance to about 35 Ω. The iris can be used in itself as an impedance transformer, but if the iris is to match a large impedance, it will have a narrow bandwidth. Since there is already a low impedance in front of the iris, the iris coupling will have a broader bandwidth. It is to be noted that if the quarter-

wave transformer effect is to be utilized, the resonator must have a fairly high dielectric constant.

Referring to Fig. 3, there are two parasitic elements 8 placed on the surface of the resonator 6. Depending on the design of and matching requirements regarding the transition, even a larger number of parasitic elements 8 can be added. The elements have the same resonant frequencies or they are tuned to a slightly different frequency than the resonant frequency of the metal strip 7.

In the dielectric piece, many different waveforms can propagate if evoked. Table 1 shows the so-called critical frequencies of waveforms m, n propagating in the dielectric piece in this example, in a waveguide R 58; ε_r = 10.5 and the unit of frequency GHz.

Table 1

m, n	0	1	2	3	4	5	6
0	0	1.1461	2.2922	3.4383	4.5844	5.7305	6.8766
1	2.2924	2.5630	3.2418	4.1322	5.1256	6.1720	7.2486
2	4.5849	4.7259	5.1259	5.7309	6.4836	7.3389	
3	6.8773	6.9721	7.2492				

Of these, evoked waveforms are those which have an even index n and an odd index m, because these waveforms have a symmetry in both horizontal and vertical symmetry levels, as do the iris at the end of the waveguide and the metal strip. Some of these waveforms may resonate in the dielectric resonator. Fig. 4 illustrates such a resonator. The dielectric piece can be thought of as seeing its mirror image behind its ground plane, on the right in Fig. 4, which gives the piece a half-wave thickness.

Referring further to the German patent specification DE 4208458, the specification starts out from

a patch aerial, which has been developed into a transition. In the transition of the invention, the starting point is that power is coupled in the structure via the coupling iris between the microstrip and the waveguide. Placed in front of the coupling iris is a plate having a thickness of about $\lambda/4$ and a high dielectric constant, which acts as a quarter-wave transformer and as a dielectric resonator. The transition functions well even in this form, but it can be further improved if a suitable metal strip is placed in front of the quarter-wave transformer or dielectric piece. The essential property of the structure is that it utilizes the quarter-wave transformer effect achieved by using a high dielectric constant. Also, making use of the resonances created in the quarter-wave thick plate as a phenomenon improving the bandwidth is a significant improvement with respect to the German specification referred to.

The invention is not limited to the application examples presented above, but many variations are possible within the scope of the inventive idea defined by the claims.

CLAIMS

1. Microstrip-to-waveguide transition in the micro and/or millimetre wavelength range, said transition comprising a waveguide (1), a microstrip (3) placed at one end of the waveguide, and a ground plane (4) with a coupling iris (5) between the microstrip and the waveguide, **characterized** in that the transition is provided with a resonator (6) consisting of dielectric material and placed below the coupling iris (5) in the waveguide (1) for the coupling of power via the coupling iris to the resonator and further to the waveguide.

2. Microstrip-to-waveguide transition as defined in claim 1, **characterized** in that the resonator (6) is implemented as an impedance transformer, preferably a quarter-wave transformer, the resonator having a thickness (d) of about $\lambda/6$ - $\lambda/3$, preferably about $\lambda/4$ in the longitudinal direction of the waveguide (1), where λ corresponds to the wavelength at the operating frequency in the dielectric material.

3. Microstrip-to-waveguide transition as defined in claim 1 or 2, **characterized** in that the resonator (6) extends to the ground plane (4).

4. Microstrip-to-waveguide transition as defined in any one of claims 1 - 3, **characterized** in that the resonator's dielectric constant ε_r is about 2 - 15, advantageously about 6 - 10 and preferably about 7.5.

5. Microstrip-to-waveguide transition as defined in any one of claims 1 - 4, **characterized** in that the size of the coupling iris (5) is so chosen that the resonant frequency of the coupling iris is below the operating frequency of the transition.

6. Microstrip-to-waveguide transition as defined in any one of claims 1 - 5, **characterized** in that the resonator comprises a metal strip (7) placed

on the opposite side of the resonator (6) relative to the coupling iris (5).

7. Microstrip-to-waveguide transition as defined in any one of claims 1 - 6, **characterized** in that the ground plane (4) with the coupling iris (5) is comprised in the microstrip (3).

8. Microstrip-to-waveguide transition as defined in any one of claims 1 - 8, **characterized** in that it comprises at least two parasitic elements (8) placed on the surface of the resonator (6) in parallel with the metal strip (7), the resonant frequency of said parasitic elements being tuned to a frequency differing from that of the metal strip.

9. Microstrip-to-waveguide transition as defined in any one of claims 1 - 9, **characterized** in that the waveguide (1) has a rectangular, round, polygonal or elliptic shape in cross-section.

10. Microstrip-to-waveguide transition as defined in any one of claims 1 - 10, **characterized** in that the shape of the cross-section of the coupling iris (5) and/or metal strip (7) corresponds to the cross-sectional shape of the waveguide (1).

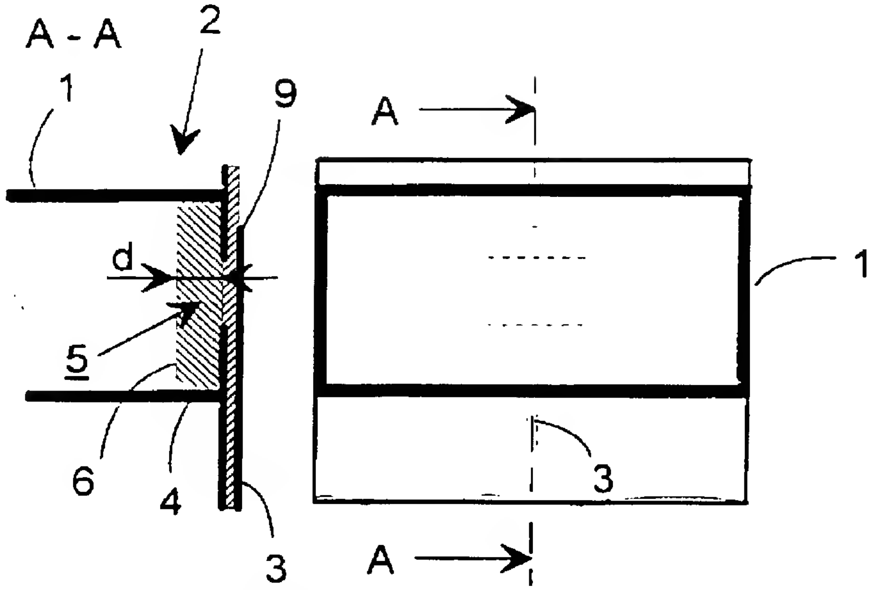

Fig 1

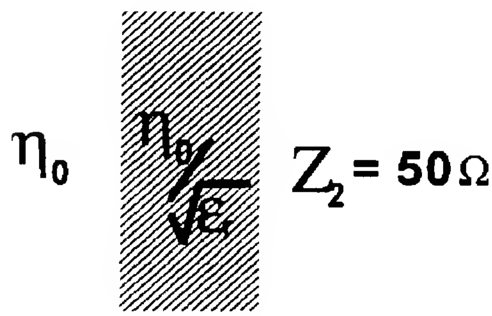

Fig 2a

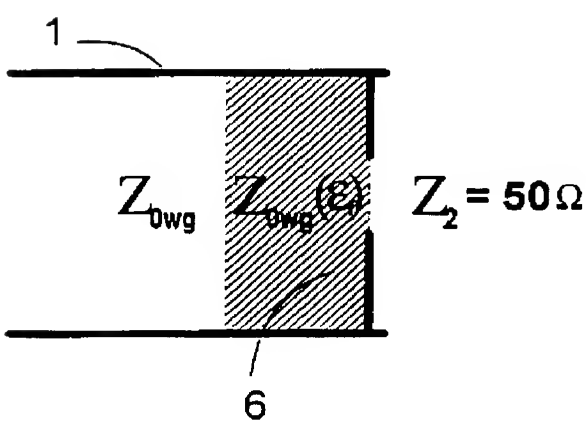

Fig 2b

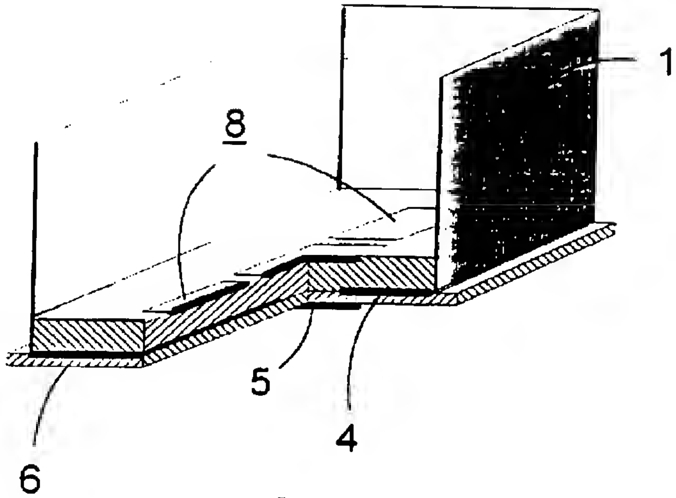

Fig 3

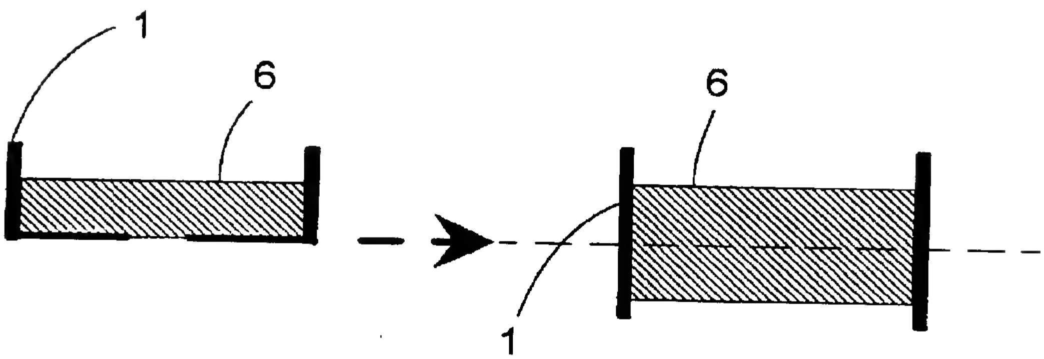

Fig 4

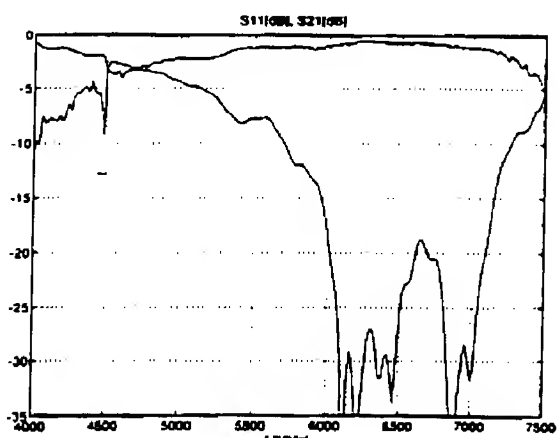

Fig 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 96/00130

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01P 5/107
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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IPC6: H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5202648 A (JAY H. MCCANDLESS), 13 April 1993 (13.04.93), figure 1, abstract --	1-10
A	US 4733202 A (GERARD FORTERRE ET AL), 22 March 1988 (22.03.88), figure 3, abstract --	1-10
A	DE 4208058 A1 (DEUTSCHE AEROSPACE AG), 16 Sept 1993 (16.09.93), cited in the application --	1-10
P,A	DE 4329570 A1 (DEUTSCHE AEROSPACE AG), 9 March 1995 (09.03.95), figures 1,2, abstract --	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

01/04/96

International application No.
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 5202648	13/04/93	NONE	
US-A- 4733202	22/03/88	CA-A- 1256518	27/06/89
		EP-A,A,B 0223673	27/05/87
		SE-T3- 0223673	
		FR-A,B- 2589283	30/04/87
		JP-A- 62102603	13/05/87
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